



8th International Conference on Asian and Pacific Coasts (APAC 2015)

Effect of Artificial Vegetation on Wave Attenuation – An Experimental Investigation

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Abstract

In the wake of threats posed by rising sea levels and increasing severity of storms, the use of soft measures in coastal protection is acquiring an ever increasing importance. Coastal vegetation acts as a complex interface ecosystem between human communities and the sea and provides important ecosystem services by protecting these communities from coastal hazards, providing critical habitat for fishes and marine invertebrates and primary food source for animals like sea turtles. This paper tries to bring out the effect of simulated vegetation on wave attenuation through an experimental study. The tests were carried out with submerged artificial seagrass and artificial rigid vegetation in a 50 m long wave flume. For wave heights ranging from 0.08 m to 0.16 m at an interval of 0.02 m and wave periods 1.8 s and 2 s in water depths of 0.40 m and 0.45 m, measurements of wave heights at locations along the vegetation were observed.

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Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015

Keywords: Coastal protection; shoreline vegetation; submerged seagrass and rigid vegetation; wave attenuation.

1. Introduction

Shoreline vegetation acts as a buffer zone against wave attack on rear side of the beaches. Strips of vegetation at the water's edge act as a bio-shield which reduces the impact of cyclones, storm surges and tsunamis. The Indian

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Ocean tsunami that hit the Indian coast on 26 December 2004 has raised concern on coastal vulnerability and consequently, measures to protect our coasts has become a prime concern. Sustainable coastal protection for mitigating flooding and erosion is of great interest in the present day scenario of global climate change and rising sea levels. Reports have shown that some of the villages which were behind the mangrove and shelterbed plantations in Tamilnadu suffered considerably less damage as the intensity of the tsunami was weakened by these natural barriers.

The presence of coastal vegetation can attenuate the wave height as well as the wave energy. Previous studies to establish the effectiveness of coastal vegetation on wave attenuation include studies on internal wave attenuation by coastal kelp stands (Jackson, 1984), wave damping as a result of local energy losses due to a cluster of cylinders which represents a dense stand of giant kelp (Dalrymple et al., 1984), flume observations of velocity and turbulence intensity profiles in eelgrass beds in a large seawater flume (Gambi et al., 1990), and field investigations of water flow in a *Spartina maritima* salt-marsh in southern Portugal (Neumeier and Ciavola, 2004). Neumeier and Amos (2006) investigated the processes of turbulence reduction and attenuation of orbital velocities in a *Spartina anglica* salt-marsh in east England. Augustin et al. (2009) conducted laboratory experiments to measure wave attenuation resulting from synthetic emergent and nearly emergent wetland vegetation under a range of wave conditions and plant stem densities. The effects of submergence ratio on wave attenuation, transmission and energy dissipation over the model of seagrass *Posidonia oceanica* were investigated in a large-scale flume facility (Stratigaki et al., 2011).

Coastal environments are part of a fragile and dynamic ecosystem. The removal of vegetation from these environments can have far reaching effects. The anthropogenic causes of marine habitat destruction are deforestation in the hinterland, dredging and reclamation for construction of harbours and jetties, anchoring and moving of boats and ships, discharge of chemical effluent and runoff and untreated sewage disposal.

2. The role of vegetation in wave damping

Ocean waves are propagating energy in waveform through orbital motion of water particles. The energy of a wave is related to the square of its height (Dean and Dalrymple, 2001) as

$$E = \frac{1}{8} \rho g H^2 \quad (1)$$

where, E is the energy per unit surface area (J/m^2), ρ is the density of water (kg/m^3), g is the acceleration due to gravity (m/s^2) and H is the wave height (m). Eq. (1) holds well within the limits of the small-amplitude wave theory. As the waves propagate towards the shore and encounters shallower water, the wavelength and hence, the wave speed decrease. As the waves slow down, the wave energy and correspondingly the wave height increases in order to maintain the total amount of energy flux, and consequently an amplification of wave height due to shoaling is observed (Schwartz, 2005). As waves approach the shore, friction between the water particles and the seabed results in energy loss. This loss of energy due to bottom friction is observed prior to wave breaking. The presence of vegetation meadow near the surface can attenuate the wave energy as they offer frictional resistance to particle movement and cause wave breaking. Vegetation penetrates through the layers of varying particle orbital velocities, resulting in an increase in turbulence and loss of energy and consequently, wave breaking. The presence of pockets of mud, large stands of seaweed, pile clusters, or submerged trees interferes with the wave orbital velocities, which causes an increase in turbulence and loss of energy. The localized energy dissipation at the bottom of or throughout the water column causes the incident wave field to diffract as well as attenuate (Dalrymple et al., 1984).

3. Objective

The objective of the present experimental investigation is to determine the wave height attenuation through submerged artificial vegetation acted upon by varying wave climate.

4. Details of experimental work

4.1. Wave Flume

Experiments with artificial vegetation are conducted in a two dimensional wave flume of the Marine Structures Laboratory of the Department of Applied Mechanics and Hydraulics at National Institute of Technology Karnataka, Surathkal, India. The flume is 50 m long, 0.71 m wide and 1.1 m deep (schematized in Fig. 1).

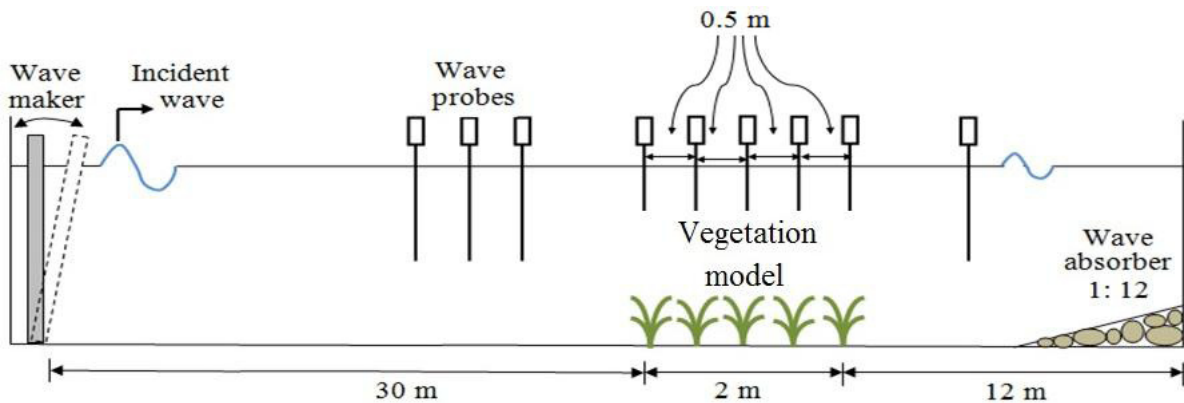


Fig. 1. Schematic experimental setup

Waves are generated using a bottom hinged flap which is housed in a 6.3 m long, 1.5 m wide and 1.4 m deep chamber. The flap is controlled by an induction motor of 11 kW at 1450 rpm, which in turn is regulated by an inverter drive (0-50 Hz) rotating in a speed range of 0-155 rpm. Monochromatic waves of heights 0.08 m to 0.24 m and periods 0.8 sec to 4.0 sec in a maximum water depth of 0.5 m can be generated with this facility. A rubble mound wave absorber is placed at the other end to minimize reflection from the end of the flume.

4.2. Instrumentation

Four capacitance-type wave probes along with amplification units are used in the present experimental study to measure water surface elevation. The data acquisition system consists of a host computer for on-line display, recording and analysis of responses from the wave probes. A Matlab program based on the Isaacson's three probe method is employed for separating the incident and reflected components of the signals recorded by the wave probes.

4.3. Test model and test conditions

The experiments are conducted using two types of submerged artificial vegetation. The first model, *Vegetation Model 1* (referred to as *Model 1*) is a submerged seagrass model of height 0.21 m, prepared from 0.0001 m thick polyethylene plastic sheets and the second model, *Vegetation Model 2* (referred to as *Model 2*) is a submerged rigid plant model of nylon rods of height 0.16 m and diameter 0.008 m. In order to replicate the original vegetation in the field, a suitable material for the model is selected based upon the Young's modulus of natural vegetation. This

is a measure of stiffness of the elastic material and is used to characterize the material property. The modulus of elasticity value for seagrasses is in the range 0.4 GPa to 0.8 GPa (Folkard, 2005), and that for common timber is in the range 10.05 GPa to 15 GPa. In order to cover this range of E , a reference value of 0.7 GPa and 11.5 GPa is assumed for the seagrass and the rigid vegetation respectively for the field condition. A model scale of 1:30 is adopted to scale down the prototype values, which would mean that the Young's modulus value of the model material should be about 0.023 GPa and 0.383 GPa respectively, which is quite difficult to identify. Therefore, instead of modelling Young's modulus, E and the second moment of area, I separately, the stiffness property, EI is modelled as a single parameter. Polyethylene, with an E value of about 0.6 GPa and nylon with an E value of about 3 GPa is selected for simulating the real seagrass leaves and the rigid vegetation trunks. Having chosen the material for the model, the typical prototype dimensions of seagrass leaves are in the range of 0.5 to 1.5 m and the diameter of the vegetal stems are in the range of 0.4 to 0.5 m. The vegetal models used for the experiments have been shown in Fig. 2.

Model 1 has 0.01 m high stipes, 0.21 m long leaves and is placed at a spacing of 0.005 m. Each simulated plant is composed of 4 to 5 polyethylene leaves and is attached to 1 m x 0.73 m x 0.02 m slabs in a staggered distribution. *Model 2* is constructed by fixing rigid nylon rods in holes drilled in 1 m x 0.73 m x 0.04 m concrete slabs. The rods are 0.008 m in diameter and 0.16 m long. Both the models of 2 m length are placed over the flume bed, 30 m away from the wave flap and are tested separately.

Table 1. Vegetation characteristics and experimental conditions.

Artificial plant type	Vegetation model characteristics		Meadow width (m)	Wave height (m)	Wave period, T (s)	Water depth, d (m)	Relative plant height (h/d)
Seagrass (<i>Model 1</i>)	Modulus of Elasticity	0.6 GPa	2	0.08, 0.10, 0.12, 0.14, 0.16	1.8, 2	0.40, 0.45	0.525, 0.47
	Thickness of leaf	0.0001 m					
	Length of leaf	0.21 m					
	Width of leaf	0.004 m					
	Plant density	10000 shoots/m ²					
Rigid vegetation (<i>Model 2</i>)	Modulus of Elasticity	2 – 4 GPa	2	0.08, 0.10, 0.12, 0.14, 0.16	1.8, 2	0.40, 0.45	0.4, 0.36
	Length of rod	0.16 m					
	Diameter of rod	0.008 m					
	Rod spacing	0.05 m					

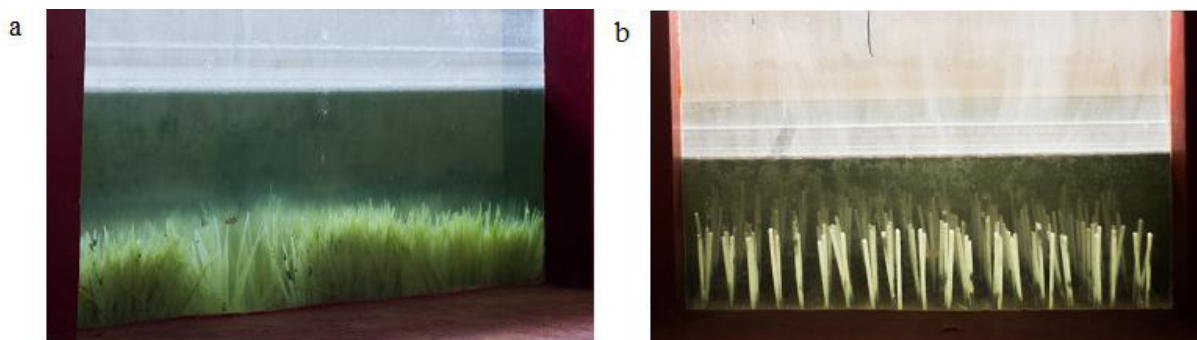


Fig. 2. Model setup to study wave attenuation over (a) *Model 1*: Seagrass; (b) *Model 2*: Rigid vegetation.

The 2 m long test section is subjected to normal attack of waves of characteristics as described in Table.1. Wave probes are used to measure the incident wave height (H_i), the transmitted wave height (H_t) and the wave heights within the artificial vegetation meadow. This paper addresses the influence of long waves on wave height attenuation through the artificial meadow.

5. Results and Discussion

In order to evaluate the effect of submerged vegetation on wave propagation, the variation of wave height along the vegetation meadow is measured for different wave conditions. Results are presented as graphs of wave heights (H_x) measured for every 0.5 m (expressed as percentage of total meadow width) within the vegetation meadows, and graphs of wave transmission coefficient, K_t (measured at 1 m beyond the meadow) against wave steepness (H/L).

5.1. Wave height attenuation by submerged vegetation

The measured wave height at locations within the vegetation models is shown in Fig. 3. It is seen that the wave height decreases exponentially as it propagates through both the vegetation models. Vegetation causes wave attenuation because it acts as an obstacle for the wave propagation. This dissipates a significant portion of the energy of the waves, thereby reducing the wave height.

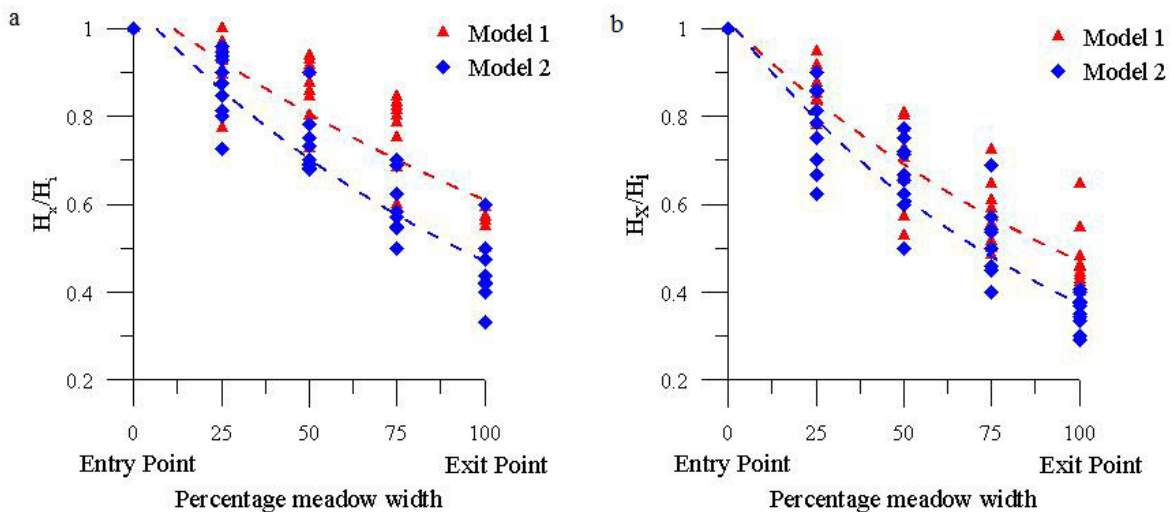


Fig. 3. Measured wave height at locations within the vegetation models tested in water of depth a) $d=0.45$ m b) $d=0.40$ m

For depth of water, $d = 0.45$ m, wave heights are decreasing within the meadow and at the end of the meadow, it is only 60% of that at the entry point for *Model 1*, while it is about 47% of that at the entry point for *Model 2*. Similarly, for water depth, $d = 0.40$ m, wave heights decrease within the meadow and at the end point of the meadow, it is only 48% of that at the entry point for *Model 1*; and for *Model 2* it is only 38% of that at the entry point. Comparing the models in both the cases, it can be seen that *Model 2* is more efficient in wave height reduction.

For $d = 0.40$ m, it is seen from Fig. 3b that the wave height at the end of the meadow for *Model 1* is 48%, which shows a better attenuation for the same model at $d = 0.45$ m where the wave height is 60% of that at the entry point (see Fig. 3a). Similarly for *Model 2* tested in a water depth, $d = 0.40$ m, in the Fig. 3b, the wave height at the end of the meadow is 38% when compared to a higher wave height of 47% for the same model at $d = 0.45$ m (Fig. 3a).

Considering all the test conditions, it is clear that *Model 2* (rigid vegetation) in a water depth, $d = 0.40$ m exhibits increased wave height reduction and minimum wave transmission at the end point of the meadow and therefore is more efficient compared to *Model 1* (seagrass).

5.2. Variation of transmission coefficient (K_t)

With the vegetation meadow in place it is seen from Fig. 4a and 4b that K_t decreases with increase in H/L . This is because the 2 m wide meadow and the height of the vegetation are successfully interfering with the wave propagation resulting in friction, turbulence and wave breaking. This gives rise to reduced wave energy on the lee side thus decreasing K_t .

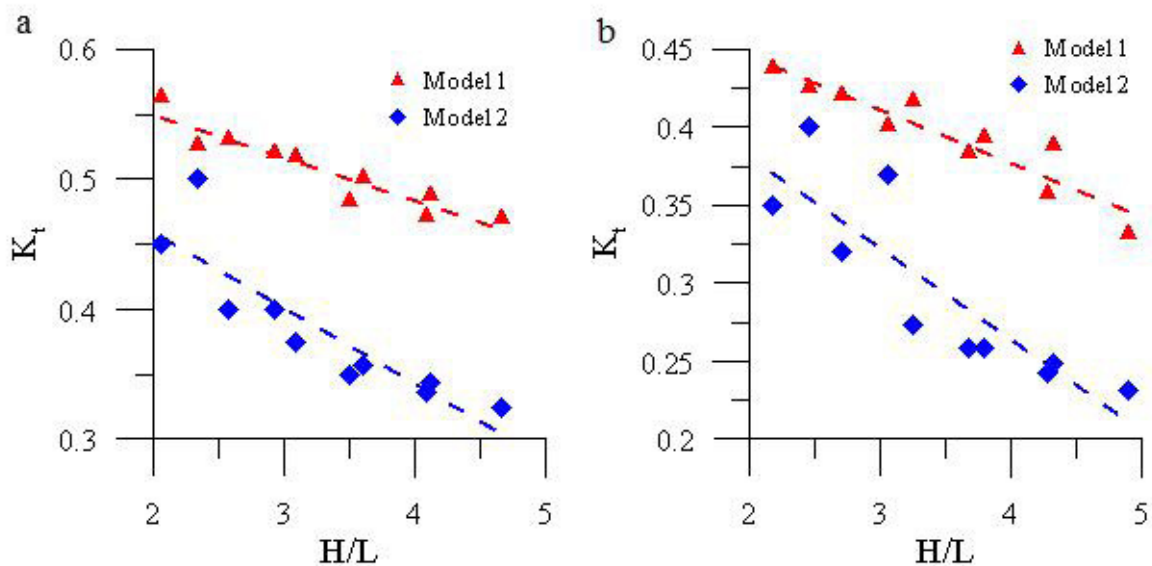


Fig. 4. K_t vs. H/L for different vegetation models tested in a water depth a) $d=0.45$ m b) $d=0.40$ m.

For a depth of water, $d=0.45$ m, it is seen from Fig. 4a that K_t decreases from 0.55 to 0.48 for *Model 1* and from 0.45 to 0.3 for *Model 2*. This shows that the *Model 2* is better than *Model 1* in reducing the wave height. Similarly, for depth of water, $d = 0.40$ m, as in Fig. 4b, K_t decreases from 0.44 to 0.36 for *Model 1* and from 0.375 to 0.22 for *Model 2*, which shows that *Model 2* effectively reduces the wave height and thereby the wave transmission.

As depth of water decreases from 0.45 m to 0.40 m, it is seen that the value of K_t decreases from 0.55 to 0.48 and from 0.45 to 0.36 for *Model 1*. Similarly, for *Model 2*, as the depth of water is reduced to 0.40 m from 0.45 m, K_t varies from 0.375 to 0.22 and from 0.45 to 0.3 respectively. From the above it is very clear that *Model 2* is relatively more efficient in reducing the transmitted waves.

6. Conclusions

The attenuation of waves is a function of vegetation characteristics such as type of vegetation, height, density, and stiffness as well as the wave characteristics. Wave heights exponentially decay over the vegetation meadow. As the depth of water is reduced from 0.45 m to 0.40 m, both the models exhibit increased efficiency in wave height reduction and wave transmission. *Model 2* (rigid vegetation) is 9 % to 13 % more efficient than *Model 1* (seagrass). *Model 2* exhibits lowest K_t values of 0.375 to 0.22. The rigid vegetation model (*Model 2*) is superior to seagrass model (*Model 1*) in wave height reduction and reduced wave transmission.

Acknowledgements

The authors are thankful to the Director of National Institute of Technology Karnataka, Surathkal, and Head of the Department of Applied Mechanics and Hydraulics for the facilities provided for the investigation and permission granted to publish the results.

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